

# Outcomes of Fenestrated/Branched Endografting in Post-dissection Thoracoabdominal Aortic Aneurysms

K. Oikonomou <sup>a,b</sup>, R. Kopp <sup>a</sup>, A. Katsargyris <sup>a</sup>, K. Pfister <sup>a</sup>, E.L. Verhoeven <sup>b</sup>, P. Kasprzak <sup>a,\*</sup>

<sup>a</sup> Department of Surgery, Division of Vascular Surgery, University Hospital Regensburg, Regensburg, Germany

<sup>b</sup> Department of Vascular and Endovascular Surgery, Paracelsus Medical University, Nürnberg, Germany

## WHAT THIS PAPER ADDS

To the authors knowledge this is the largest study in the literature on fenestrated/branched endografting for patients with extensive post-dissection TAAA. The study demonstrates that fenestrated/branched endografting is feasible and may become a promising alternative in the treatment of this complex type of pathology.

**Objectives:** Fenestrated/branched thoracic endovascular repair (F/Br-TEVAR) is increasingly applied for atherosclerotic thoracoabdominal aortic aneurysm (TAAA); however, use in post-dissection TAAAs is still very limited. Experience with F/Br-TEVAR in the treatment of post-dissection TAAA is presented.

**Methods:** Data were analysed from prospectively maintained databases including all patients with post-dissection TAAAs that underwent F/Br-TEVAR within the period January 2010 to July 2013 in two vascular institutions. Evaluated outcomes included initial technical success, operative mortality and morbidity, late survival, endoleak, aneurysm diameter regression, renal function, and reintervention during follow-up (FU).

**Results:** A total of 31 patients (25 male, mean age  $65 \pm 11.4$  years) were treated. Technical success was 93.5% and 30-day mortality 9.6%. Temporary spinal cord ischaemia occurred in four (12.6%) patients, with no case of permanent paraplegia. Mean FU was  $17.0 \pm 10$  months. There were seven late deaths, all aneurysm unrelated. Estimated overall survival rates were  $83.9 \pm 6.7$ ,  $76.4 \pm 7.9$  and  $71.6 \pm 8.7\%$  at 6, 12, and 18 months, respectively. Impairment of renal function occurred in two (6.4%) patients. Endoleaks were diagnosed in 12 patients during FU, including six type IB endoleaks and six type II endoleaks. Reintervention was required in seven (22.5%) patients. Mean aneurysm sac regression was  $9.3 \pm 8.7$  mm, with a false lumen thrombosis rate of 66.7% and 88.2% for patients with a FU longer than 6 and 12 months respectively.

**Conclusions:** F/Br-TEVAR is feasible for patients with a post-dissection TAAA. Although associated with additional technical challenges, and a significant need for reintervention, it leads to favourable aneurysm morphologic changes, and may play a more prominent role in the future for this type of pathology if long-term results confirm the good initial outcome.

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## INTRODUCTION

A large proportion of patients suffering acute aortic dissection will develop a post-dissection aneurysm, regardless of type and treatment in the acute setting.<sup>1,2</sup> This long degenerative process is characterized by extensive remodelling of the aorta and increasing fibrotic stiffness of the intimal flap, resulting in an aneurysm with specific technical challenges. Open thoracoabdominal aneurysm (TAAA) repair is very demanding and associated

with high mortality and morbidity.<sup>3,4</sup> Standard thoracic endovascular aneurysm repair (TEVAR) can be a viable approach for secondary aneurysms limited to the thoracic aorta.<sup>5</sup> However, as most post-dissection aneurysms involve both the thoracic and abdominal aorta, complete aneurysm exclusion is only feasible using fenestrated/branched stent-grafts.

Fenestrated and branched TEVAR (F/Br-TEVAR) has demonstrated favourable early and mid-term outcomes for atherosclerotic TAAAs.<sup>6–8</sup> However, specific literature on F/Br-TEVAR in the treatment of patients with post-dissection TAAAs is still sparse.<sup>9–11</sup> Following publication of initial clinical experience in six patients 2 years ago, extended outcomes of the technique in 31 consecutive patients treated with F/Br-TEVAR for post-dissection TAAAs in two centres experienced in advanced endovascular techniques are now presented.<sup>9</sup>

\* Corresponding author. P. Kasprzak, Department of Surgery, Division of Vascular Surgery, University Hospital Regensburg, Franz Josef-Strauss-Allee 11, 93053, Regensburg, Germany.

E-mail address: [piotr.kasprzak@ukr.de](mailto:piotr.kasprzak@ukr.de) (P. Kasprzak).

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## MATERIALS AND METHODS

### *Patient population*

Prospectively maintained databases from two vascular institutions were analysed for patients who underwent elective F/Br-TEVAR for TAAA between January 2010 and July 2013. Patients with chronic thoracoabdominal aneurysmal degeneration following Type A or Type B dissection extending through the visceral segment were included in the study. An aneurysm diameter of 55 mm or greater was considered an indication for treatment. Informed consent was obtained for all patients. The study was approved by the appropriate ethical committees of both institutions.

### *Operative planning*

Preoperative planning was carried out using thin cut ( $\leq 1.5$  mm) spiral computerized tomography angiography (CTA) from the chest to the groins on three-dimensional (3D) workstations featuring multiplanar reconstruction and centerline of flow analysis. The physical status of all patients was assessed preoperatively by the American Society of Anaesthesiologists (ASA) score.

All patients were treated with custom-made branched and/or fenestrated Cook endografts based on the Zenith system (William A. Cook Australia, Ltd., Brisbane, Australia). A variety of endograft configurations was used. A proximal tube graft was applied in cases of narrow true lumen ( $< 20$  mm), designed with 10–15% oversizing to the proximal thoracic aorta and distal landing zone 2–3 cm above the first targeted visceral artery. The next graft included the fenestrations and/or branches. Caudally oriented side branches were preferably used in cases of caudal vessel take-off and adequate true lumen size ( $> 20$  mm) at the level of the target vessel. Reinforced fenestrations were applied in patients with small true lumens and when the target vessel had a 90-degree take-off. In the case of accessory renal arteries, the decision to revascularize was determined by the diameter of the artery and the amount of renal volume dependent on the vessel. Accessory renal arteries with a diameter  $< 3$  mm were overstented. Branches were secured with self-expandable Fluency stent-grafts (C. R. Bard, Murray Hill, NJ, USA) in the first institution. In the second institution, branches were either secured with balloon-expandable Advanta V12 stent-grafts (Atrium Medical Corporation-Hudson, NH, USA) or self-expandable Fluency stent-grafts for stent-graft lengths  $> 8$  mm. Fenestrations were secured with Advanta V12 stent-grafts. In cases of severe angulation of the target vessel an additional SMART (Cordis, Warren, NJ, USA), Wallstent (Boston Scientific, Natick, MA, USA) or Zilver (William A. Cook Australia, Ltd., Brisbane, Australia) self-expandable bare metal stent was deployed inside the covered stent to prevent kinking.

Vessels originating from the false lumen were targeted with fenestrations/branches. A standard catheterization attempt was first carried out with the support of a guiding sheath. When unsuccessful, the back of a 0.035-inch

Terumo wire (Terumo Corporation, Tokyo, Japan) or a Rösch-Uchida set (William A. Cook Australia, Ltd., Brisbane, Australia) for transjugular intrahepatic portosystemic shunt (TIPS) procedures was used to perforate the dissection flap.

Distal sealing was obtained below the level of the dissection at the level of the distal abdominal aorta, the common iliac arteries, or the external iliac artery whenever needed.

Preservation of the left subclavian artery and pelvic circulation was always targeted, to reduce the risk of paraplegia. This was achieved by the use of carotid–subclavian debranching or an additional fenestration for the left subclavian artery and the use of an iliac bifurcation device (IBD) in cases of common iliac artery involvement.

### *Endovascular procedure*

In the first institution procedures were initially carried out in the operating room with a mobile C-Arm (OEC 9900 Elite, General Electric Healthcare, WI, USA) and from January 2012 in a hybrid operating room with fixed imaging (Allura Xper FD20, Philips Medical Systems, Best, The Netherlands). In the second institution all procedures were carried out in a hybrid operating room with fixed imaging (Artis Zeego, Siemens AG, Forchheim, Germany). The main operative technique has been described in detail previously.<sup>12</sup> Patients were treated under general anaesthesia. Heparinization was applied aiming to maintain an activated clotting time (ACT) of 200–250 s. A spinal catheter was applied in all cases and spinal fluid was drained from the start of the procedure until 48–72 hours after completion. For this duration patients were routinely transferred to the intensive care unit (ICU) and systolic blood pressure was kept normal to high to increase perfusion of the spine through the collateral circulation. Access was transfemoral with an additional left transaxillary approach for caudally oriented side branches.

To reduce the risk of paraplegia, a staging strategy was tested in one of the two institutions. One of the branches was intentionally left unsecured primarily, and a bridging stent-graft was applied 2–4 weeks after the initial procedure. This strategy was only introduced recently and in a limited number of patients.

Technical success was defined as an endovascularly completed procedure with absence of type I or III endoleak and patent target vessels.

### *Follow-up*

Postoperatively, patients were evaluated with clinical and laboratory examination prior to discharge. Follow-up (FU) consisted of CTA at 1 month, 6 months, 12 months, and yearly thereafter. CTAs were carried out using an arterial and a delayed phase to determine the status of the false lumen (patent/thrombosed) and the possible existence of endoleak. Duplex ultrasound (DUS) was additionally applied to assess the status of vessels targeted with fenestrations/branches. Renal size measurements were carried out on CTA 3D reconstruction images as well as DUS examinations.

Upon suspicion of a new endoleak or target vessel malperfusion digital subtraction angiography (DSA) was carried out. Serum creatinine and glomerular filtration rate (GFR) levels were monitored at each visit.

### Data analysis

Data analysis was performed with SPSS for Windows (version 20.0; SPSS Inc, Chicago, IL, USA). Variables are presented as mean  $\pm$  standard deviation (SD) in the case of normal distribution, and median plus range if data had a skewed distribution. Statistical significance was set at  $p < .05$ . Patient survival and target vessel patency was analysed using Kaplan–Meier methodology.

## RESULTS

### Patient characteristics

A total of 31 patients (25 male, mean age  $65 \pm 11.4$  years) underwent elective F/Br-TEVAR for post-dissection TAAA. Twenty (64.5%) patients were classified as ASA III, five (16.1%) patients as ASA II and six (19.4%) patients as ASA IV. Patient demographics are presented in Table 1. Mean pre-operative GFR was  $58.3 \pm 15.0$  mL/min/1.73 m<sup>2</sup>.

Median interval from the primary acute dissection was 31 months (range 1–176 months). In 22 (71%) patients, the primary event was a type B dissection, in the remaining nine (29%) patients a type A dissection. Table 2 demonstrates the number and type of prior aortic procedures, as well as the length of aorta covered during the initial procedure. Of the 24 patients with prior procedures 15 (62.5%) had been treated in an acute setting while 9 (37.5%) had been previously treated for chronic dissection.

Mean maximal aneurysm diameter at the time of F/Br-TEVAR was  $65.7 \pm 8.5$  mm. In patients with no previous proximal aortic reconstruction, the mean length of the proximal landing zone was  $43 \pm 25$  mm. Two (6.4%) patients had a proximal landing zone  $<20$  mm at the level of the left subclavian artery, and in two (6.4%) patients the aneurysmal degeneration reached the iliac artery bifurcation. Table 3 shows aneurysm diameter, true lumen diameter at the level of the celiac trunk, and the origin of all target vessels (true or false lumen).

**Table 1.** Patient comorbidities and prior acute events.

Comorbidity risk factor	Patients N (%)
CAD	20 (64.5)
Congestive heart failure	10 (32.3)
Hypertension	27 (87)
Chronic obstructive pulmonary disease	17 (54.8)
Smoking (current or past)	22 (70.9)
Diabetes mellitus	4 (12.9)
Hypercholesterolemia	25 (80.6)
Serum Cr $> 100$ $\mu$ mol/L	10 (32.3)
Previous stroke/transient ischaemic attack	2 (6.4)
Marfan syndrome	1 (3.2)
<b>Acute event</b>	
Type A dissection	9 (29.0)
Type B dissection	22 (71)

**Table 2.** Previous aortic procedures and length of aortic coverage distal to the left subclavian artery during these procedures.

Previous aortic procedures	Patients N (%)
No procedure	7 (22.5)
1 procedure	9 (29.0)
2 procedures	12 (38.7)
3 procedures	3 (9.6)
<b>Type of previous procedure</b>	
Ascending aortic repair	1 (3.2)
Ascending aortic and arch repair	6 (19.4)
Elephant trunk procedure	1 (3.2)
Frozen elephant trunk procedure	1 (3.2)
Descending aortic repair	5 (16.1)
TEVAR	21 (67.7)
Abdominal aortic repair	3 (9.6)
EVAR	4 (12.9)
<b>Length of coverage from LSA</b>	
No coverage (no previous repair)	7 (22.5)
5–10 cm	3 (9.6)
11–15 cm	4 (12.9)
16–20 cm	10 (32.3)
$>20$ cm	7 (22.5)

### Operative planning and details

In all patients, composite fenestrated/branched systems were applied. The composite system consisted of a thoracic component followed by a tube graft containing the fenestrations/branches in 11 (35.4%) patients. In the remaining 20 (64.5%) patients an additional Zenith bifurcated graft and a contralateral limb were used. Two (6.4%) patients with common iliac artery aneurysms and extension of the dissection into the external iliac artery were treated with composite systems featuring a unilateral IBD. In two (6.4%) patients with an inadequate proximal landing zone the left subclavian artery was preserved by means of carotid–subclavian bypass in one patient and an additional subclavian fenestration in the second patient.

In total 113 visceral vessels (57 renal arteries, 2 accessory renal arteries, 31 superior mesenteric arteries and 23 celiac arteries) were targeted, 78 with fenestrations and 35 with downward branches. Target vessel revascularization is demonstrated in Table 3. Target vessels were dissected prior to F/Br-EVAR in five out of 113 cases. An additional self-expandable bare metal stent was applied in 27 of the 113 (23.8%) targeted vessels. These were Smart stent in 11 (9.7%), Wallstent in 10 (8.8%) and Zilver stent in the remaining six (5.3%) cases. Thirteen vessels were not targeted. Eight of these vessels (5 renal arteries and 3 celiac arteries) were primarily occluded. In one case the celiac artery had been overstented and in one debranched to the superior mesenteric artery in a previous external attempt to treat the aneurysm with a standard thoracic endograft. Two celiac arteries were severely stenosed and were overstented. In one case a planned surgical reimplantation of the celiac artery onto the superior mesenteric artery (SMA) was carried out during the procedure via an upper midline incision because of a very sharp caudal vessel take-off with extremely narrow true aortic lumen, which made planning

**Table 3.** Dissection characteristics with specification of true lumen size at the level of the coeliac.

Patients	An diam (mm)	TL diam (mm)	RRA	TL/FL	LRA	TL/FL	SMA	TL/FL	CA	TL/FL	Distal graft
1	72	11 × 22	Fen	FL	Fen	TL	Branch	TL	Occl		Bifurc
2	73	15 × 28	Fen	FL	Fen	TL	Fen	TL	Sten	TL	Bifurc
3	64	48 × 64	Branch	TL	Branch	TL	Branch	TL	Branch	TL	Tube
4	68	31 × 38	Fen	TL	Fen	TL	Fen	TL	Branch	TL	Tube
5	67	8 × 21	Fen	TL	Fen	FL	Fen	TL	Reimpl	TL	Bifurc/IBD
6	71	16 × 27	Fen	TL	Fen	FL	Fen	TL	Fen	TL	Bifurc
7	67	38 × 27	Fen	TL	Fen	TL	Branch	TL	Occl		Bifurc/IBD
8	72	15 × 25	Fen	TL	Fen	TL	Branch	TL	Branch	TL	Tube
9	63	12 × 23	Occl		Fen	TL	Fen	TL	Fen	TL	Tube
10	63	18 × 35	Fen	TL	Fen	TL	Fen	TL	Branch	TL	Tube
11	70	17 × 50	Fen	TL	Fen	TL	Branch	TL	Branch	TL	Tube
12	68	15 × 22	Fen	TL	Fen	TL	Fen	TL	Branch	TL	Tube
13	55	15 × 20	Branch	TL	Occl		Branch	TL	Occl		Bifurc
14	88	17 × 31	Fen	TL	Fen	TL	Fen	TL	Branch	TL	Tube
15	60	11 × 28	Fen	TL	Fen	TL	Fen	TL	Branch	TL	Bifurc
16	75	8 × 27	Occl		Fen	TL	Fen	TL	Sten		Bifurc
17	55	25 × 25	Fen	TL	Occl		Fen		Debr		Bifurc
18	74	8 × 30	Fen	TL	Fen	TL	Fen	TL	Fen	TL	Bifurc
19	68	20 × 20	Fen	TL	Fen	TL	Fen	TL	Fen	TL	Tube
20	55	12 × 20	Fen	FL	Branch	FL	Branch	TL	Branch	TL	Bifurc/IBD
21	55	12 × 25	Fen	TL	Fen	FL	Fen	TL	Fen	TL	Bifurc
22	81	50 × 70	Branch	TL	Branch	TL	Branch	TL	Branch	TL	Bifurc
23	55	35 × 35	Branch	TL	Occl		Branch	TL	Branch	TL	Bifurc
24	55	12 × 26	Fen	TL	Fen	TL	Fen	TL	Fen	TL	Bifurc
25	58	10 × 22	Fen	TL	Fen	TL	Branch	TL	Branch	TL	Bifurc
26	55	13 × 29	Fen	TL	Fen	TL	Fen	TL	Fen	TL	Tube
27	74	9 × 22	Fen	TL	Fen	TL	Fen	TL	Overst		Tube
28	67	14 × 30	Branch	FL	Fen	TL	Fen	TL	Fen	TL	Bifurc
29	70	10 × 28	Branch	TL	Branch	FL	Branch	TL	Branch	TL	Bifurc
30	60	20 × 30	Fen	TL	Fen	TL	Fen	TL	Branch	TL	Bifurc
31	58	25 × 25	Fen	TL	Fen	TL	Fen	TL	Fen	TL	Bifurc

*Note.* Artery is the origin of target vessels and fenestrated/branched stent-graft design. An = aneurysm; Diam = diameter; TL = true lumen; RRA = right renal artery; FL = false lumen; LRA = left renal artery; SMA = superior mesenteric artery; CA = celiac artery; Fen = fenestration; Occl = occluded; Bifurc = bifurcated; Sten = stenosis; Reimpl = reimplantation; IBD = iliac branched device; Debr = previous debranching; Overst = previous overstenting.

of a fenestration or branch very problematic. A staged approach was applied in three (9.7%) patients.

The procedure was carried out under general anaesthesia in all patients. A transaxillary approach was used in 17 (54.8%) patients. Median operative time was 320 minutes (range 130–690 minutes) and median estimated blood loss (EBL) 600 mL (range 100–3000 mL). Median fluoroscopy time was 66 minutes (range 24–112 minutes) and mean iodinated contrast volume used  $255 \pm 107$  mL (iodine concentration 300 mg/mL).

### Technical success and operative outcome

Technical success was achieved in 29 out of 31 (93.5%) patients. In one patient the fenestrated component was deployed into the false lumen, resulting in acute occlusion of the celiac and the superior mesenteric arteries. A laparotomy was carried out, followed by a prosthetic bypass from the right iliac artery to the superior mesenteric, hepatic, and splenic arteries. In the second patient catheterization of a highly angulated left renal artery originating from the false lumen was not feasible through femoral

access. This patient had a stent-graft featuring a branch for the celiac artery, which was primarily left unsecured for paraplegia prevention. Catheterization of the left renal artery by a transbrachial approach during the second stage of the procedure was planned.

Three early deaths occurred, accounting for a 30-day mortality of 9.7%. The first patient developed multiple organ failure on the first postoperative day after an uneventful endovascular procedure with complete exclusion of the aneurysm and patent target vessels on the completion angiogram. Computed tomography angiography (CTA) showed no sign of target vessel occlusion, but demonstrated renal and intestinal microinfarction. The second patient suffered a deterioration of cardiac function following a technically successful procedure, ultimately resulting in cardiac failure and death. Finally, the third case involved the patient with the unsuccessful renal artery catheterization. During the second procedure via a transbrachial approach he suffered a perforation of the left subclavian artery, resulting in mediastinal bleeding and death.

Major complications occurred in five (16.1%) patients. Four (12.9%) suffered temporary spinal cord ischaemia with paraparesis ( $n = 2$ ) or paresis of one limb ( $n = 2$ ). All four patients had patent subclavian and internal iliac arteries. In one of these patients spinal cord ischaemia occurred despite staged treatment with a graft featuring an unsecured branch for paraplegia prevention. This patient developed transient paraparesis after the second procedure, which resolved with spinal cord drainage and blood pressure regulation. All patients recovered fully until the time of discharge. Finally, one (3.2%) patient required temporary dialysis. This patient had previous open surgery which had resulted in paraparesis and impaired renal function. Renal function recovered after 6 weeks. His paraparesis did not worsen after the endovascular procedure. This patient stayed in hospital for 37 days. No other case of renal function deterioration  $>30\%$  was witnessed in the early postoperative period. Mean postoperative GFR was  $55.7 \pm 15.7$  mL/min/1.73 m<sup>2</sup>.

Median hospital stay was 12 days (range 7–37 days) and median ICU stay 3 days (range 1–30) days.

### Follow-up

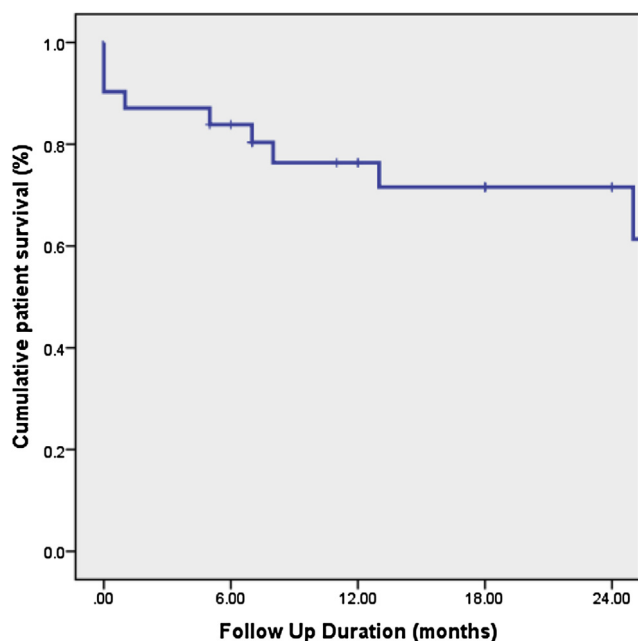
Mean FU was  $17.0 \pm 10$  months. Estimated overall survival rates were  $83.9 \pm 6.7$ ,  $76.4 \pm 7.9$  and  $71.6 \pm 8.7\%$  at 6, 12, and 18 months, respectively (Fig. 1). All-cause late mortality during FU was seven patients, all aneurysm unrelated. In three cases, patients were preoperatively classified as ASA IV.

During FU two cases of target vessel occlusion occurred. In the first patient the left renal artery, originally targeted with a branch and secured with a Fluency stent-graft, occluded at 2 months, following a deterioration of his pre-existing congestive heart failure with prolonged hypotension. The second patient had a small renal artery

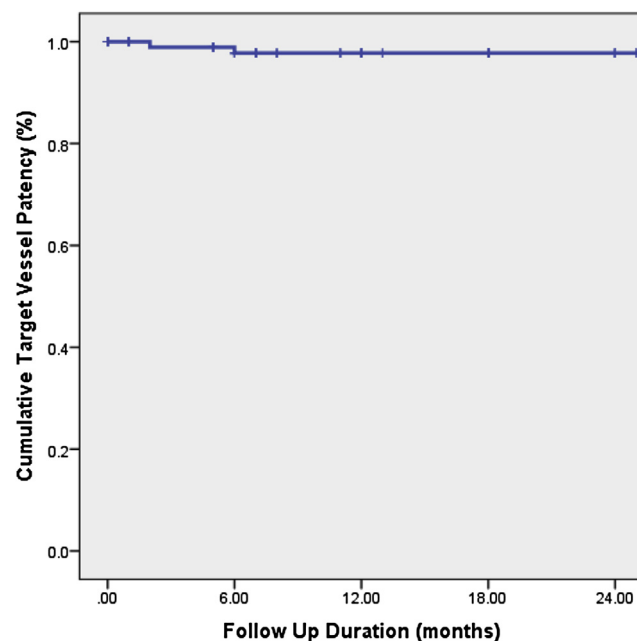
originating from the false lumen, perfusing a smaller kidney. This vessel had been targeted with a fenestration. The patient presented with an asymptomatic occlusion at 6 months. Cumulative target vessel patency at 6 months was  $97.8 \pm 1.1\%$  (Fig. 2). No other target vessel occlusion or haemodynamically significant stenosis was visualized on DUS or CTA during FU. Renal function and kidney size remained unchanged in 26 out of 28 (92.8%) patients surviving the early postoperative period. In two patients, late renal function problems occurred: The first patient suffered from chronic kidney disease prior to the procedure and became dialysis dependent following occlusion of his left renal artery. The second patient requiring temporary dialysis after the procedure became dialysis dependent again 5 months postoperatively. Mean GFR during FU was  $53.8 \pm 9.7$  mL/min/1.73 m<sup>2</sup>.

Endoleaks were detected in 12 patients during FU. Type Ib endoleaks were detected in 6 (19.3%) patients. Three (9.6%) of these patients had a type Ib endoleak from the distal sealing zone in the left renal artery. In one of these patients the left renal artery was dissected prior to F/Br-EVAR. One (3.2%) patient had distal type Ib endoleaks from both renal arteries. These vessels were also primarily dissected. One (3.2%) patient had distal type Ib endoleaks from the superior mesenteric and the right renal artery. In all patients vessels had been secured with Advanta V12 stent-grafts and with an additional self-expanding stent to tape the dissection flap in the case of primarily dissected vessels. The sixth patient had a distal type Ib endoleak originating from a dissected left common iliac artery. The remaining six (19.3%) patients had type II endoleaks from the inferior mesenteric ( $n = 3$ ) and lumbar ( $n = 3$ ) arteries.

In total, 10 patients required reintervention, including the three patients that underwent planned staged procedures.



**Figure 1.** Kaplan—Meier estimate of the cumulative overall patient survival for all-cause mortality during follow-up.



**Figure 2.** Kaplan—Meier estimate of the cumulative target vessel patency during follow-up.



Seven (22.5%) patients required unplanned reintervention. Five of the six patients with a distal type Ib endoleak were successfully treated with extension of the balloon-expandable covered stent into the target visceral vessel (Fig. 3). The sixth patient with a type Ib endoleak from the left iliac artery underwent two reinterventions. The endoleak was initially treated with an IBD in the left internal iliac artery. Upon persistence of the endoleak over the also dissected internal iliac artery, the IBD was embolized and a bypass from the ipsilateral external to the internal iliac artery was carried out. Finally, the seventh case involved a patient with an extensive type II endoleak from a lumbar artery who underwent embolization 6 months post-operatively. Reintervention times are demonstrated in Table 4.

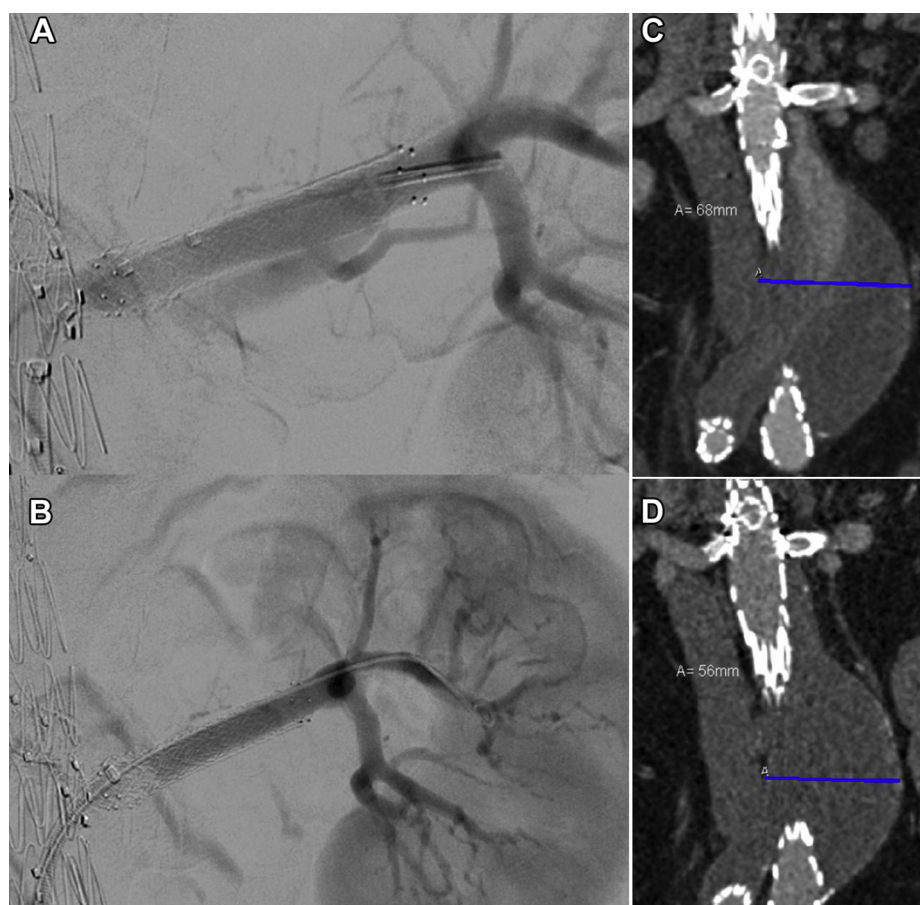
Of the 24 patients that completed a 6-month FU, complete false lumen thrombosis was noted in 16 (66.7%) patients. At 1 year, false lumen thrombosis was seen in 15 out of 17 (88.2%) patients. Mean aneurysm sac regression during FU was  $9.3 \pm 8.7$  mm. Initial sac enlargement was noted in six of the seven patients requiring reintervention. Successful treatment of type Ib endoleaks led to false lumen thrombosis and sac regression. Aneurysm sac behaviour in patients that completed a 12-month FU is demonstrated in Table 5.

## DISCUSSION

A rigorous FU is required following an acute thoracic aortic dissection, regardless of primary treatment. In our series 24 out of 31 (77.5%) of patients had undergone one or more previous procedures, 62.2% of patients had been treated in the acute setting. Although this is a selected patient population, this could reflect the increased need for future intervention as survival of patients with acute dissection improves.

Open repair of post-dissection TAAA poses serious technical problems and significant risk for the patient. Studies from specialized, high-volume centres including both post-dissection and atherosclerotic TAAAs report a 30-day mortality rate of 5–8% with a paraplegia risk approaching 6–8% after open thoracoabdominal repair.<sup>4,13,14</sup> Renal complications develop in 17–25% of patients with up to 15% requiring haemodialysis. These results reflect the extensive experience of high-volume centres. Analysis of volume-related outcomes over a wider range of hospitals reveal the “real-world” picture, with overall mortality reaching 22.3% and postoperative complication rates exceeding 55%.<sup>3,15</sup>

Although fenestrated and branched grafts are increasingly used for atherosclerotic TAAAs, their use for post-



**Figure 3.** Persistent type Ib endoleak from the left renal artery (A) over a renal side branch. The endoleak was treated by implantation of an Atrium Advanta V12 stent-graft into the distal portion of the artery (B). Computed tomography angiography prior to (C) and 1 year after (D) the reintervention show complete thrombosis of the false lumen and aneurysm sac regression.

**Table 4.** Type of endoleak and reintervention time.

Endoleak type	Time of reintervention (months)
Ib LRA	7
Ib LRA	14
Ib LRA	9
Ib RRA, SMA	4
Ib RRA, LRA	2
Ib CIA	5;12
II Lumbar artery	6

LRA = left renal artery; RRA = right renal artery; SMA = superior mesenteric artery; CIA = common iliac artery.

dissection TAAA is limited to a few specialized centres, due to the rarity of cases and added technical complexity of F/Br-TEVAR in chronic dissection. This series suggests that F/Br-EVAR can be feasible in patients with post-dissection TAAA. Technical success was high and early mortality comparable to published results on F/Br-EVAR for non-post-dissection TAAAs.<sup>7</sup> Despite the significant rate of temporary spinal cord ischaemia, no case of permanent paraplegia was noted. The renal complication rate was low. Target vessel patency remained high and no aneurysm related mortality was noted during FU. Notably, three of seven late deaths occurred in patients preoperatively classified as ASA IV, underlining the need for a cautious approach in patients with severe comorbidities. To the author's knowledge this is the largest study in the literature on F/Br-TEVAR for patients with extensive post-dissection TAAA. Apart from the authors previous report, there is one more paper featuring 30 patients with smaller focal ( $n = 15$ ) and extensive ( $n = 15$ ) dissections.<sup>9,10</sup>

Despite the promising initial outcome, additional difficulties in planning and execution of the procedure have to be expected. Typically, the true lumen in post-dissection TAAAs is oblique and narrow. Fenestrated devices might therefore seem more suitable, since they require less space for deployment than branched devices. Placing of the clock positions on fenestrations can however be problematic, as one should take into account the highly compressed true lumen. Deployment of the device usually results in expansion of the true lumen and subsequent rearranging of target

vessel ostia. On the other hand, branches are easier to plan and facilitate catheterization of target vessels with a sharp take-off over a transaxillary access. In order to create enough working space for the placement of a branched device, a long proximal stent-graft is applied landing distally 2–3 cm above the orifice of the celiac artery. Kitagawa et al.<sup>10</sup> propose staging the procedure for ~2 months to allow for expansion of the true lumen. In this series, pre-conditioning of the false lumen with a proximal component was not staged. Our strategy was to apply a moderate oversizing of 10–15% to the proximal aorta and remodel the true lumen only partially. Whether a more aggressive oversizing and a staged approach might offer advantages is a point to follow in future reports.

Another dissection-specific difficulty relates to visceral branches originating from different lumina. In such cases, catheterization of target vessels can be achieved by perforating the dissection flap with a needle (e.g. TIPPS needle) or the stiff end of a wire, in conjunction with a guiding sheath.

The choice of landing zone can also be problematic in post-dissection TAAA. In cases where a prior surgical or endovascular landing zone has successfully been created during a previous procedure, no issues with proximal sealing, fixation, or migration are to be expected. When this is not the case, it is mandatory to preserve flow in the subclavian artery to diminish the risk of paraplegia. The same issue arises at the level of the iliac arteries. When necessary, the distal sealing zone should include the iliac bifurcation, while ensuring flow into the internal iliac artery by the use of an IBD. Applying this strategy, no case of permanent paraplegia was noted in this series. However, spinal cord ischaemia obviously remains a consideration when carrying out extensive endovascular thoracoabdominal repair.

Finally, the increased need for reintervention should be noted. In two of five patients presenting with type Ib endoleaks from visceral vessels, these were dissected prior to F/Br-EVAR. Endoleaks occurred despite primary implantation of an additional self-expanding stent into the dissected vessel, indicating that especially when the dissection progresses deep into a target vessel, retrograde aneurysm perfusion through the false lumen may require multiple procedures to treat. In the case of post-dissection TAAAs, a longer initial sealing zone into the target vessel seems to be mandatory than in atherosclerotic TAAAs. Regarding type II endoleaks, these should be expected but have a benign course and spontaneously seal over time, similar to atherosclerotic aneurysms. Ultimately, the false lumen thrombosis rate after reintervention was high in patients that completed a 12-month FU, indicating that F/Br-EVAR could be a durable treatment option for post-dissection TAAAs.

This study has some limitations. The number of patients and duration of FU are limited. This is a selected patient population and a certain referral bias has to be acknowledged. Finally, this study reflects the outcomes of two high-volume centres for F/Br-TEVAR.

**Table 5.** Aneurysm sac behaviour in relation to thrombosis of the false lumen in patients with a 12-month follow-up.

	False lumen thrombosis		Total
	Yes	No	
Decrease (<–5 mm)	13 <sup>a</sup> (76.4%)	1 <sup>b</sup> (5.9%)	14 (82.3%)
Stable (–5 mm to 5 mm)	2 (11.8%)	1 <sup>b</sup> (5.9%)	3 (17.6%)
Increase (>5 mm)	0	0	0
Total	15 (88.2%)	2 (11.8%)	17 (100%)

<sup>a</sup> Five patients with initial sac expansion after F/Br-EVAR. Following reintervention complete false lumen thrombosis and aneurysm sac regression.

<sup>b</sup> Patients with a type II endoleak from lumbar arteries.

In conclusion, F/Br-EVAR shows promising results and could play a more prominent role in the future in patients with post-dissection TAAA. It is nevertheless associated with additional technical challenges and requires rigorous FU in the light of the increased need for reinterventions. Larger series and longer FU are needed to confirm the good initial outcome.

### CONFLICT OF INTEREST

Piotr Kasprzak is consultant for Cook, W.L. Gore & Associates, Bard, Atrium, and Aptus. Eric Verhoeven is consultant for Cook, W.L. Gore & Associates, Siemens, and Atrium.

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### REFERENCES

- 1 Fanelli F, Dake MD. Standard of practice for the endovascular treatment of thoracic aortic aneurysms and type B dissections. *Cardiovasc Intervent Radiol* 2009;**32**:849–60.
- 2 Fattori R, Montgomery D, Lovato L, Kische S, Di Eusanio M, Ince H, et al. Survival after endovascular therapy in patients with type B aortic dissection: a report from the International Registry of Acute Aortic Dissection (IRAD). *JACC Cardiovasc Interv* 2013;**6**:876–82.
- 3 Cowan Jr JA, Dimick JB, Henke PK, Huber TS, Stanley JC, Upchurch Jr GR. Surgical treatment of intact thoracoabdominal aortic aneurysms in the United States: hospital and surgeon volume-related outcomes. *J Vasc Surg* 2003;**37**:1169–74.
- 4 Coselli JS, Bozinovski J, LeMaire SA. Open surgical repair of 2286 thoracoabdominal aortic aneurysms. *Ann Thorac Surg* 2007;**83**:862–4.
- 5 Kang WC, Greenberg RK, Mastracci TM, Eagleton MJ, Hernandez AV, Pujara AC, et al. Endovascular repair of complicated chronic distal aortic dissections: intermediate outcomes and complications. *J Thorac Cardiovasc Surg* 2011;**142**:1074–83.
- 6 Verhoeven EL, Tiellu IF, Bos WT, Zeebregts CJ. Present and future of branched stent grafts in thoraco-abdominal aortic aneurysm repair: a single-centre experience. *Eur J Vasc Endovasc Surg* 2009;**38**:155–61.
- 7 Guillou M, Bianchini A, Sobocinski J, Maurel B, D'elia P, Tyrell M, et al. Endovascular treatment of thoracoabdominal aortic aneurysms. *J Vasc Surg* 2012;**56**:65–73.
- 8 Greenberg R, Eagleton M, Mastracci T. Branched endografts for thoracoabdominal aneurysms. *J Thorac Cardiovasc Surg* 2010;**140**:171–8.
- 9 Verhoeven EL, Paraskevas KI, Oikonomou K, Yazar O, Ritter W, Pfister K, et al. Fenestrated and branched endovascular treatment of post-dissection chronic aortic aneurysms after initial treatment in the acute setting. *J Endovasc Ther* 2012;**19**:343–9.
- 10 Kitagawa A, Greenberg RK, Eagleton MJ, Mastracci TM, Roselli EE. Fenestrated and branched endovascular aortic repair for chronic type B aortic dissection with thoracoabdominal aneurysms. *J Vasc Surg* 2013;**58**:625–34.
- 11 Trimarchi S, Righini P, Grassi V, Lomazzi C, Segreti S, Rampoldi V, et al. Do branched and fenestrated devices have a role in chronic type B aortic dissection? *J Cardiovasc Surg* 2011;**52**:529–38.
- 12 Verhoeven EL, Zeebregts CJ, Kapma MR, Tiellu IF, Prins TR, van den Dungen JJ. Fenestrated and branched endovascular techniques for thoraco-abdominal aneurysm repair. *J Cardiovasc Surg* 2005;**46**:131–40.
- 13 Misfeld M, Sievers HH, Hadlak M, Gorski A, Hanke T. Rate of paraplegia and mortality in elective descending and thoracoabdominal aortic repair in the modern surgical era. *Thorac Cardiovasc Surg* 2008;**56**:342–7.
- 14 Wong DR, Parenti JL, Green SY, Chowdhary V, Liao JM, Zarda S, et al. Open repair of thoracoabdominal aortic aneurysm in the modern surgical era: contemporary outcomes in 509 patients. *J Am Coll Surg* 2011;**212**:569–79.
- 15 Rigberg DA, McGory ML, Zingmond DS, Maggard MA, Agustin M, Lawrence PF, et al. Thirty-day mortality statistics underestimate the risk of repair of thoracoabdominal aortic aneurysms: a statewide experience. *J Vasc Surg* 2006;**43**:217–22.